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Grazing Research in the Humid East: A Historical Perspective

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ABSTRACT

A historical perspective of the major developments in grazing research for the humid Eastern USA was addressed. Consideration was given to the emergence of the area of grazing research relative to the initial structure of agricultural institutions, the orientation of scientist within the constraints of the institutional boundaries (departments) and the carry-through noted today. Early grazing research was constrained to the informal literature and discussed as informational, demonstrational, and experimental. The milestones that have been achieved, including statistical application, conceptual assessment, description of grazing management, methods of computing pasture yields, the origin and use of put-and-take stocking, pasture and animal biomass relationships, choice of stocking method, flexible grazing, and measurements in recent grazing research are presented and discussed relative to their origin and application. Furthermore, consideration was given to a number of important innovations with origin in the humid East that have contributed to the advancement of grazing research. Finally, brief consideration is given to future priority areas of grazing research and associated constraints.

Grazing research is a multidisciplinary area of study that integrates the soil, plant, and animal, with the environment superimposed. The emergent structure that formed early in the humid Eastern USA in agricultural research institutions, be it public (State Agricultural Experiment Stations or USDA Research Stations) or private, generally placed the plant and animal disciplines into separate and physically independent sections (departments) with subsequent development of rigid administrative and fiscal boundaries. This structure was not favorable to the development of grazing, as an area of research, because the component disciplines were never formally linked. For example, responsibility for grazing research resided neither in the animal science nor in the plant science sectors or departments, but grazing trials were conducted in each. These early trials resulted in incomplete data with limited utility as grazing trials conducted under the animal disciplines lacked plant characterization, and trials conducted under the plant disciplines lacked animal characterization. As the animal and plant disciplines grew and developed, the problem became more exaggerated as individuals were hired that were trained to think and work within the constraints of their departmental or sectional boundaries (Fig. 1).

Such compartmentalization resulted in animal-disciplined individuals being concerned mainly with animal-oriented problems and forage or pasture-disciplined individuals concerned mainly with plant- and soil-oriented problems. Consequently, the integration of the plant and animal areas for grazing research was problematic from the start and has been slow to emerge. In fact, it can be argued that this separation of plants from herbivores may be the underlying cause as to why the ruminant-animal industry that developed in the humid East has, as its focus, mainly animal husbandry. This is in contrast to a ruminant industry that is grassland based, where producers are grassland farmers and the focus is on forage and pasture production and its efficient utilization. Grassland farming would seem to have been a natural evolution in the humid East, occurring throughout the mountain regions and into the South and Southeast where open winters prevail. The reality is that the ruminant industry in the humid East is an industry of value-added products that is essentially 100% dependent on the primary industry of grasslands (including legumes and legume–grass mixtures), but remains viewed as animal husbandry. Furthermore, the artificial separation of plants from ruminants probably encouraged animal nutritionists to explore alternative sources of feeds, which generated nutritional problems and thus the associated need for specific nutritional research. This likely encouraged the early development of dry-lot feeding concepts which, with the help of cheap feed grains acting as an economic incentive, emerged rapidly.

As the historical aspects of grazing research are addressed in this paper, it is important to understand that it was from within such a framework that grazing research slowly emerged, and continued to retain much of its original structure. This is evidenced at this writing by considering two prominent USDA-ARS animal research locations, each with a national mission. One facility is a dairy research center located north of Madison, WI. As part of the planning process for a national dairy–forage program, beginning in 1974, I was a member (co-chairman) of the Southern Regional Dairy-Forage Task Force Committee to provide a situation report (Dairy–Forage Task Force Report, Southern Region) to the National Planning Committee (on which I later held membership). The resulting report (Fortmann and Plowman, 1975) to the Assistant Secretary for Conservation, Research and Education, stressed the importance of regional forage–dairy programs because of pasture–species diversity and the opportunity for forage (pasture)–animal research. The Madison location essentially provides little to no opportunity for the conduct of grazing research with lactating cows and would have little pertinence to most of the eastern grasslands of the USA. The other facility is dedicated to beef cattle (*Bos taurus* L.) research and is located at Clay Center, NE. This location has a beef

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Abbreviations: TDN, total digestible nutrients.

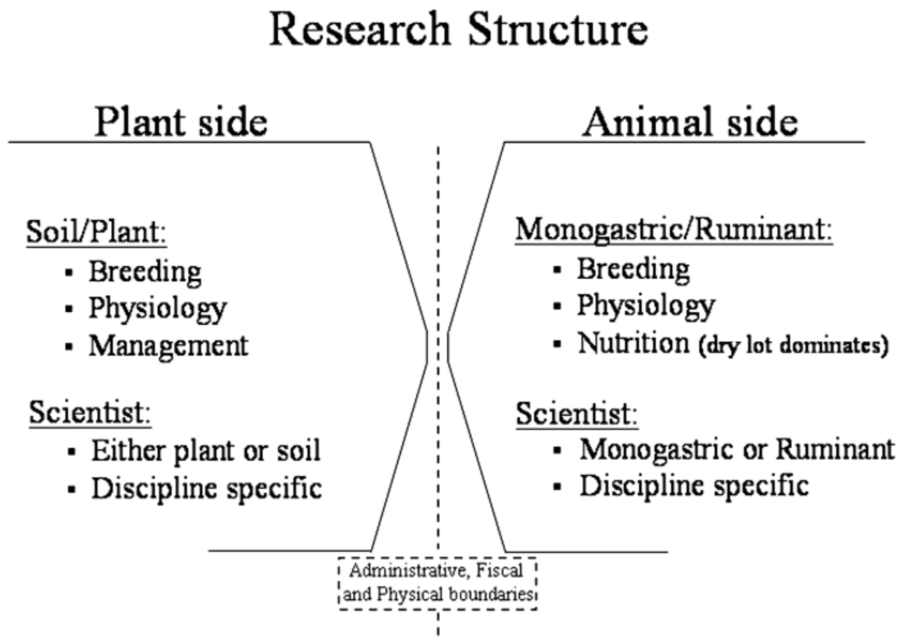

Fig. 1. Formal departmental (physical) structure with administrative and fiscal responsibilities delineated for the conduct and accountability of either plant or animal research. Functional plant–animal research must be laid across these normally rigid boundaries.

cattle program with an engineering component (added as Phase II), but no forage component. In 1979, I, along with several other scientists active in grazing research, participated in a planning session to develop a plan for grazing research at the Clay Center facility which had been designated as Phase III (Graumann, 1980). This phase, to be cooperative with the University of Nebraska, was never implemented. In both instances, valuable research is being conducted, but pasture-oriented scientists are nonexistent at either facility and grazing research is not a priority in their animal programs. Granted, some multidisciplinary USDA-ARS grazing research programs were evident early on, for example at the Beltsville, MD, location, but these were terminated by the mid-1970s.

In general, most innovations in grazing research and the recent emergence of multidisciplinary programs have occurred at universities with some being joint with USDA and including USDA-ARS scientists. In those settings, forage scientists and ruminant-animal scientists with a keen interest and desire to conduct grazing research can readily interact. It is from frequent informal discussions that valuable forage–animal interface studies emerge that permit a better understanding of grassland farming through well planned and properly conducted grazing research. The concept of team research has been delineated in terms of pros and cons, including the responsibility of Scientist and Administration, by Burns et al. (1988). Figure 2 provides an example of a working structure, giving consideration to the conceptual assessment (addressed later; Lucas, 1962a) that I formalized in 1975 showing the operational interaction of the cooperative forage–animal research program at Raleigh, NC [USDA-ARS and North Carolina Agriculture Research Service (ARS) cooperating]. Such an arrangement, predicated on federal and state cooperation, permitted the plant–animal interface to emerge because program ownership was shared across departments, agencies, and scientific disciplines. Success occurs from such a cooperative arrangement when all participants can demonstrate a major benefit.

EARLY GRAZING RESEARCH

Formal Documentation

It seems appropriate to initially document early grazing research (i.e., replicated pastures and hypothesis testing) as opposed to demonstrations (unreplicated pastures with data summary and simply reporting) in the humid eastern USA through a search of the domestic literature beginning in the early 1900s. Journals considered were the *Journal of the American Society of Agronomy* (volume 1 issued in 1907 and renamed the *Agronomy Journal* in 1950), *The American Society of Animal Production* (issued 1910 as the *Record of Proceedings of the Annual Meetings*) and renamed in 1942 the *Journal of Animal Science*, and the *Journal of Dairy Science* (volume 1 issued in 1917), and *Crop Science* (volume 1 issued in 1961). The first replicated grazing trial, with associated statistical analyses, was published in the *Journal of Animal Science* in 1945. It was conducted in Virginia and authored by Kincaid et al. (1945). This was followed in 1947 by a paper authored by M.L. Petersen from Iowa State University and published in the *Journal of the American Society of Agronomy* (Petersen, 1947). Before those dates, reports of grazing-demonstration results were initially published in 1919 in the *Journal of the American Society of Agronomy* (Shepperd, 1919), in 1929 in the *American Society of Animal Production* (Parson, 1929) and in 1944 in the *Journal of the American Society of Agronomy* (Baker and Mayton, 1944). The paper by Baker and Mayton is mentioned because it was the first demonstration in a journal to report pasture productivity following a report proposing the concept by Hinman in 1937 (Hinman, 1937).

The first replicated grazing trial with dairy heifer as test animals was reported in the *Journal of Dairy Science* in 1954 by McCullough et al. (1954) and, the first replicated grazing trial using lactating dairy cows as test animals, was published in 1956 by Seath et al. (1956) and Lassiter et al. (1956). In

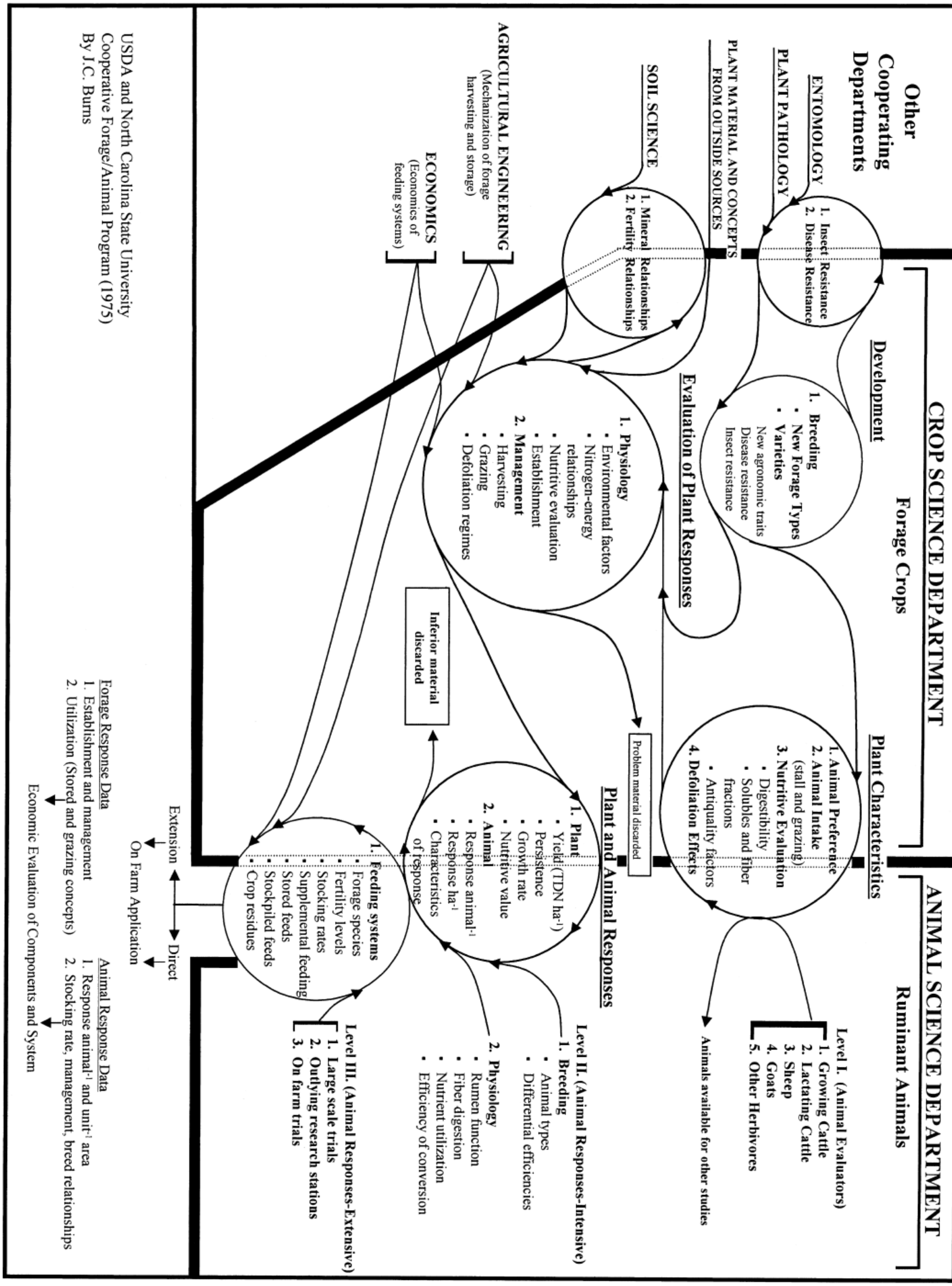

Fig. 2. Example of a functional plant–animal research program laid across departmental boundaries encompassing multidisciplines in a joint federal–state research program.

the same volume of *Journal of Dairy Science*, Pratt and Davis published the first grazing experiment using a protein–grain mixture fed as a variable supplement to cows grazing a legume–grass pasture (Pratt and Davis, 1956). It is worthy to note that the 39th volume (1956) of the *Journal of Dairy Science* contained 12 articles which addressed pastures for the grazing dairy animal.

Although *Crop Science* was first issued in 1961, publication of the first replicated grazing trial did not occur until some 20 yr later (Marten et al., 1981). However, before the grazing trial authored by Marten et al., several studies were published concerning the palatability of forages (Buckner and Burrus, 1962; Craigmiles et al., 1964; Gangstad, 1966).

The general absence of grazing research data in the journal literature until the mid-1940s to 1950s seems rather peculiar, especially considering that the topic of pasture techniques and utilization was being addressed in a special symposium as early as 1924 by the *American Society of Agronomy* (Carrier, 1924; Fain, 1924) and by special reports in 1950 in the *Journal of Animal Science* (Beeson et al., 1950), followed by a book on pasture and range techniques published in 1952 (Pasture Improvement Committee, 1952). This disparity is discussed below under headings concerning research needs, place of publication, and the role of publications.

Research Needs

As part of a symposium held in 1924 (noted above) addressing "the forage problem," Carrier (1924) made a presentation on tame grasses in the humid North and Fain (1924) addressed the semiwastelands of the Southern Coastal Plains. Following are some quotes from their papers which provide some insight into the conditions at that time that probably influenced the development of grazing research.

The returns per acre from grazing are low. In some parts of the country they are not sufficient to pay the fixed cost of taxes, labor, and the cost of wintering the animals necessary to maintain the industry–*Carrier, 1924*

While the returns are low in most parts of the country the outlay is still lower–Carrier, 1924

Too many conclusions in regards to the handling of tame pasture of the humid regions have been drawn from experience gained in bunch grass regions of the dry range country–*Carrier, 1924*

There are 5 mo of feed and 7 mo of starvation–*Fain, 1924*

The awareness to address questions that were researchable regarding grazing research was active in the 1920s and 1930s and both the pasture and animal scientists were considering the dynamics of the plant–animal system from their own (limited) perspective.

Place of Publication

The question of documentation of grazing research in the early literature (before the mid-1940s) may, in part, be made more clear by the title of a presentation made by R.W. Thatcher in 1927 "Should the results of research be published in bulletins, or in scientific journals, or both" (Thatcher, 1927). This paper was part of a symposium on "Publication of the Results of Agronomic Research" presented to the American Society of Agronomy. Further, in a grazing report (demonstration) authored by Mayton et al. (1947), several statements in the discussion reflect an attitude regarding the area of grazing research at that time and are as follows.

Because of amount of land, number of animals, and expense involved, no replication was attempted in this experiment.

Very few grazing experiments have been conducted in this country that have provided a reliable estimate of experimental error. For this reason no attempt will be made in an analyses of the results of this test to attach significance to small differences in animal gains.

Role of Publications

Before the late 1950s, little emphasis was placed on journal publication for professional advancement. Instead, the oral presentation of results at field days and their distribution by handouts, and the use of technical fliers, as well as experiment station bulletins (both general and technical) and USDA bulletins, were looked on with favor by the administration (D.S. Chamblee, active 1943 to 1991, 2004, personal communication). These less rigorous sources as outlets for grazing research data would surely influence the likely publications of grazing research data in scientific journals. In reality, however, a scientific journal that would readily accommodate results from grazing experiments was not available early on, and in fact, has really never emerged. Because of discipline structure, animal-oriented journals mainly focus on animal physiological responses and not plant assessment, and plant-oriented journals mainly focus on plant physiological responses and not animal assessment. This compartmentalization can unduly complicate publication of grazing research data. Some accommodation has recently occurred through the decision in 1990 to split the Ruminant Nutrition section in the *Journal of Animal Science* into Digestion and Metabolism and Pasture and Forage (Vol. 68, 1990), and has been recently entitled Rangeland, Forage and Pasture Utilization. Also, a name change occurred in 2001 for Division C-6 of the *Crop Science* journal (volume 4) from "Crop Quality and Utilization" to "Forage and Grazing Lands."

Considering the early economic conditions relative to animal grazing systems, the lack of statistical information on the pasture and the animal components of a grazing system, and apparently satisfactory use of informal outlets for grazing research data, it is clear that the informal literature holds the vast majority of the results from early grazing trials. Consequently, the informal literature was examined and examples of findings under several categories are discussed below.

Informal Documents

The documentation of early grazing research in the informal literature is, at best, rather tenuous. This results from the degree to which it is scattered and is not easily accessible. It is of interest to note that in 1952, Ahlgren stated, "Most of the studies involving comparison of the productivity of permanent and rotational pastures on plowable land have been conducted during the past 15 yr" (Ahlgren, 1952). This indicates that most of the improved pasture research has occurred since 1937. Efforts were made, however, to locate and document the emergence of formal grazing trials with treatments replicated before the mid-1940s to mid-1950s. It is addressed below by considering documents providing grazing information, grazing tests or demonstration, and actual grazing experiments.

Informational Documents

The very early (1890–1940) documents associated with grazing research appear to be primarily informational, as opposed to experimental, and directed to the agronomics of pastures with only limited reference to animal responses. Examples from 1894 to 1943 ranged from information on millet [*Pennisetum glaucum* (L.) R. Br.] in Michigan (Crozier, 1894), to sudangrass [*Sorghum bicolor* (L.) Moench] in Iowa (Hughes and Wilkins, 1926) and in Tennessee (Neel, 1932), to irrigated pasture for dairy cattle in Oregon (Ewalt and Jones, 1939), to general pasture management in New Hampshire (Abell, 1940), to supplementary pastures in Wisconsin (Ahlgren et al., 1941), and to pasture improvement in West Virginia (Pohlman and Cornell, 1943). General pasture handbooks (USDA) were also available (Semple et al., 1937).

Informational documents that address pasture conditions but incorporated animal response data from demonstrations seemed to emerge in the late 1920s to early 1930s and into the 1960s. Examples covering this period, in alphabetical order by state, ranged from information on permanent pasture in states such as Arkansas (Nelson, 1934), Connecticut (Brown and Slate, 1929), Louisiana (Seath, 1942), Pennsylvania (Sullivan and Graber, 1947), and South Carolina (Elting et al., 1937) to information on introduced forages for pasture. Examples of the latter are noted from Alabama (Hoveland, 1960), Florida (Blaser et al., 1955), Georgia (Burton et al., 1949; Burton, 1954), Illinois (Nevens, 1944), Iowa (Petersen and Hughes, 1948), Louisiana (Carr and Rhoad, 1943), Maryland (Hein and Cook, 1937), Michigan (Rather and Harrison, 1944), Mississippi (Skelton, 1945), South Carolina (State Pasture Committee, 1948; King et al., 1953; Woodle, 1951, 1958), and Tennessee (Van Horn and Dawson, 1948; Van Horn et al., 1956).

Demonstrations

Tests or demonstrations (nonreplicated pastures) reporting mainly animal responses from pastures also occurred during the same 1914 to 1960 time period. Examples of such test, in alphabetical order by state, occurred in Arkansas (Nelson, 1934), Florida (Ritchey and Henley, 1936; Marshall and Myers, 1959), Georgia (Stephens, 1942), Louisiana (Walker and Sturgis, 1946), Maryland (Shepherd et al., 1956), Mississippi (Gill, 1948), North Carolina (Curtis et al., 1921; Hostetler and Hankins, 1936), Ohio (Davis and Klosterman, 1959), Oregon (Ewalt and Jones, 1939), South Carolina (Elting and LaMaster, 1934), and Virginia (Carrier and Oakley, 1914).

Grazing Experiments

The use of pasture replicates in grazing experiments lacked consideration in the early years of pasture evaluation. Replicated trials become more prevalent in the late 1940s. Examples of early grazing experiments with true replicates, in alphabetical order by state, occurred in Alabama (Rollins et al., 1963), Arkansas (Spooner and Clary, 1962), Florida (Blaser et al., 1948), Georgia (Stephens and Marchant, 1959), Mississippi (Roark et al., 1953; Blount, 1958), North Carolina (Shepherd et al., 1951; Woodhouse et al., 1954, 1958), Tennessee (Parks et al., 1959; High et al., 1965; Hobbs et al., 1965), Virginia (Hunt et al., 1958), and West Virginia (Schaller et al., 1945), and on irrigated pastures in Washington (Heinemann and Van Keuren, 1960). It is interesting to note that although the publications cited had pasture replicates, only those experiments published after 1960 were analyzed statistically. The noted exceptions were Woodhouse et al. (1954) and Parks et al. (1959).

The path leading from informational documents about the value and production of pastures through to the emergence of the area of grazing research resides, for the most part, in the informal literature. A portion of this literature is appropriately being preserved by the library systems, but another portion is being preserved, at least to date, in drawers or boxes by individuals with interest in or responsibility for grazing research. The area of grazing research is slowly being eliminated from the agricultural scene, and as the present transition people retire, their documentation will be relocated to the dumpster to be forever lost. Consideration is warranted for the preservation of the informal documentation of grazing research not presently apart of the library system.

MILESTONES IN GRAZING RESEARCH

The exact documentation of specific contributions by individuals in the development and advancement of grazing research technology is difficult. This results from the frequent lag time, which can be appreciable, between conception of an idea or an approach and its actual publication. In some instances, the person to whom the original concept belongs may not have developed it sufficiently for publication or elected not to document it in the literature. Instead, the idea or concept is assumed by another and perhaps either refined, enlarged on, improved, or in someway further developed and appears in print under the latter person's name.

The milestones deemed important and discussed are mainly my opinion and I have attempted to list them in some relative chronological order. Although some milestones have had more impact than others, no effort was made to rank their importance, only to note their occurrence and application.

Statistical Application

Grazing trials without proper design and without pasture replicates to provide an estimate of experimental error are descriptive only. Such studies (demonstrations) conducted early on provided much useful and readily applicable information (Fink et al., 1933; Mitchell and Wise, 1944; Fuelleman et al., 1946), but no objective comparisons could be made among treatments.

Standard Methods

The application of simple statistics (design and analysis) with replicates of the experimental unit (pasture) provided estimates of experimental error that permitted critical comparisons of animal and pasture responses between or among treatments (Mott and Lucas, 1952). Experimental designs and analyses have been forthcoming to aid interpretation of grazing research data (Nevens et al., 1949; Thompson et al., 1955).

Special Considerations

The experimental error to be used in grazing experiments requires configuration to include both the pasture variation and the animal variation. This was addressed in 1952 by Mott and Lucas (1952) when pastures were to be stocked continuously. Somewhat different computations were needed for variable stocking, however, in which grazing periods were of shorter duration and/or animal numbers or pasture numbers varied. This aspect was addressed in 1960 by Petersen and Lucas (1960).

The potential to conduct grazing experiments without true pasture replicates, but instead use multiple stocking rates, was proposed by Riewe in 1961 (Riewe, 1961) and was followed by validation (Riewe et al., 1963). In his approach, the experimental error was estimated by deviations from regression. The importance of a reasonably uniform environment (soil and climate) as found at Riewe's location (Angleton, TX), aided the success of his approach and this was communicated to me as follows. Having visited Raleigh, NC (extremely variable soil and climate) in discussions with H.L. Lucas (North Carolina State University), Riewe allowed that he understood why Lucas routinely recommended at least three replicates for biological field experiments. The approach proposed by Riewe (1961) has been addressed by Bransby (1989), Drane (1989), and Giesbrecht (1989).

The high cost associated with grazing research prompted Matches (1988) to appeal to statisticians to develop nontraditional statistical methods that would provide valid estimates of experimental error without requiring completely balanced experiments. An example of such a method was published in 1983 by Burns et al. (1983a) which permits the replacement of inferior treatments with new treatments during the conduct of a grazing trial with a way to make valid animal and pasture response comparisons among treatments (Burns et al., 1983b).

Conceptual Assessment

An initial step in conducting research is to obtain a general understanding of the total research area and to determine which components might be most important and consequently of most interest. Thereafter, a specific experiment can be structured to address specific issues within the whole to better understand the components of interest. Because of the scope of grazing research (pastures, animal, soil, and environment), resources (facilities, funds, and personnel) are generally limited, requiring carefully designed experiments to address well thought out questions. In 1960, H.L. Lucas outlined an approach to dissect and address research areas within the pasture–animal systems (Lucas, 1960). A more detailed and expanded framework was published in 1962 (Lucas, 1962a).

Description of Grazing Management

Generally, some form of variable stocking was employed quite early on in pasture evaluation trials across the humid East. Three forms of variable stocking were categorized and defined by Mott and Lucas in 1952 as follows: (i) Using variable number of animals during the grazing season to control herbage mass (the put-and-take procedure detailed later). (ii) The use of a constant number of animals with adjustment of pasture size (or forage removal as hay) to accommodate differing pasture growth rates. (iii) The use of a constant number of animals with adjustment of season length until forage is all consumed (practiced for range condition).

Method for Computing Pasture Yield

The nutritive value and the quantity of the diet that the grazing animal consumes from a specific pasture is reflected in the animal's daily performance. Proper assessment requires knowledge about available forage which can range from excessive to limiting. The productivity of the pasture relative to animal productivity, however, requires either an estimate of the daily dry matter consumed by each animal or some other method used to calculate animal output per unit area. The concept of using animal maintenance and production requirements (in terms of energy) in reverse and reported as total digestible nutrients (TDN) was proposed as early as 1934 by Knott and Hodgson (1934), and published in the *Journal of Animal Science* in 1946 by Kidder (1946).

The concept was further developed by Lucas (1952) and Mott and Lucas (1952) in 1952, in which they proposed and outlined three methods (designated I, II, and III) of computing animal output on a unit area basis. The basic focus of their approach was to calculate the number of animal days per hectare such that animal days per unit area × average daily performance = product per unit area. Their Method I was proposed when the number of animals used was kept constant and any excess forage was not harvested but disregarded in the yield estimate. This method gave the observed yield. Method II was proposed if a variable number of animals were used such that changes in animal number occurred to either remove forage during periods of rapid growth or to reduce forage removal during periods of slow growth. This method based yields on tester performance. Method III involved the conversion of all animal responses into TDN (sometimes called the TDN method) thereby permitting the use of different classes of animals for different purposes. This method is the basis for put-and-take stocking, in which some animals are maintained on the pasture treatment all season (testers) and some animals are added or removed based on herbage mass (put-and-take or regulator animals).

Method III, proposed by Mott and Lucas (1952), is the most complex and warrants further consideration. As noted, the concept of applying feeding standards in reverse to estimate TDN (energy) occurred early in the 1930s, but the data were expressed on a *standard cow day*. The TDN was determined for all animals on a pasture treatment and divided by about 7.3 kg (estimated TDN requirement for a standard cow day). This approach, according to Petersen and Lucas (1968), did not allow for the expression of differences in the quality of the pasture relative to the level of production per animal. This concern was noted by Mott and Lucas (1952) and was addressed with a more in-depth calculation and renamed The Effective Feed Unit approach when published in 1968 by Petersen and Lucas (1968). A recent presentation of the three methods noted above for calculating pasture yield (Method I, II, and III or effective feed unit), with numeric examples of each method in a statistical setting, can be found in Petersen (1994).

Origin and Use of Put-and-Take Stocking

The actual origin of the put-and-take grazing method is rather obscure in the literature. However, some 34 yr ago in discussions with the late Dr. H.L. (Curly) Lucas (then Head, Biomathematics Division in the Department of Statistics, North Carolina State University), I learned that the concept was actually first practiced in the short-grass prairie in the Southern Great Plains. This in itself is revealing, as the general view is that the put-and-take method, considered a variable stocking approach, had its origins in the humid East because variable stocking is mainly practiced in the higher rainfall region. Dr. Lucas said that he was initially contacted by E.H. McIlvain, then superintendent, of the U.S. South Great Plains Field Station (now Southern Plains Range Research Station), Woodward, OK, to provide some assistance in data analyses from some grazing trials. Subsequent correspondence with Mr. McIlvain on the topic resulted in the following excerpts from two of his letters as noted below.

"The put-and-take grazing system–as far as I am concerned–was named by Curly Lucas or at least the group he was working with. We were using the system when we asked him to help in trying to present data from the system, but we had no name for the technique. As far as I know, the technique of putting and taking probably developed with the U.S. Forest Service personnel who conducted the early grazing studies on the Santa Rita Experimental Range near Tucson, AZ; the Jornada Experimental Range near Las Cruces, NM; the Northern Plains Experimental Range near Miles City, MT; and the Central Plains Experimental Range near Fort Collins, Colorado. D. A. Savage, who started the grazing investigations here in 1939, (I was added to the project in 1940) visited all of the above-named stations in 1939 and laid the groundwork for the technique which we used when our grazing investigations started in December 1941." (E.H. McIlvain, 2 Nov. 1972, personal communication).

In subsequent correspondence, E.H. McIlvain further clarified the origin of the concept and the actual use of this variable stocking method on range as follows.

"In answer to your recent letter on put-and-take, we are enclosing a copy of one of our early work plans. You will note the reference to changes in cattle numbers on Pages 6 and 10. These were "second thoughts." As we acquired more data in the 1940s, we found we couldn't use the gain of the "put" animals because they were not the same as those made by steers already on a treatment. Although this report is dated 1944, the principle of adjusting cattle numbers to obtain the desired degree of grazing throughout the season was used in our studies from the start, 7 Dec., 1941. Mr. D.A. Savage wasn't responsible for the original thinking on this subject. I believe he obtained it from the research stations I mentioned to you 2 Nov., 1972. E.J. Woolfolk, U.S.F.S., Miles City, Montana, was probably one of the first men to consider using the system. Our studies here may have been one of the first to use it–primarily because we were using yearling steers and not cows and calves as experimental animals."–*E.H. McIlvain, 16 Jan. 1973, personal communication*

Historically, the application of management strategies have operated in the semiarid grasslands as well as in the humid regions, and management input can range from nil, as noted for continuous, set stocking in some environments, to frequent as in rotational, variable stocking (Burns et al., 1970) in other environments. Variable stocking provides a method to equalize grazing pressure among management strategies (treatments) being evaluated (Wheeler et al., 1973). To my knowledge, the put-and-take grazing method was initially used at the Woodward Station as suggested by E.H. McIlvain and has recently been used to control herbage mass in grazing experiments conducted in the Western Great Plains (Heitschmidt et al., 1993) and more recently, in the Southern Great Plains (Coleman and Forbes, 1998).

Pasture and Animal–Biomass Relationships

The concept of grazing specific pasture treatments, such that all treatments bear the same relationship to the animal grazing, has implication in fair comparison among treatments. This concept was developed and the general response curves showing the relationship between grazing pressure and animal performance and pasture output was published by G.O. Mott (1960). Included in his publication are definitions for stocking rate, grazing pressure, and carrying capacity.

Choice of Stocking Method

Different views emerged out of the 1950s regarding the stocking method, that is, fixed continuous vs. variable, that should be used to properly evaluate pastures. This was mentioned by Lucas in 1952 and again in 1962 in his publications on designs of grazing experiments (Lucas, 1952, 1962b). Generally, fixed continuous stocking was practiced in regions of limited rainfall (Western rangelands in the USA) and/or where long dry-wet seasons dominate (i.e., northern Australia), whereas variable stocking dominated in the humid temperate regions (humid East in the USA and in Europe). New Zealand was somewhat of a mix as fixed stocking was widely practiced, but often with internal subdivision permitting a time element for pasture defoliation and regrowth.

Sparked by a lively exchange in 1970 at the XI International Grassland Congress (Surfers Paradise, Australia) following presentations on stocking methodology (Burns et al., 1970; Shaw, 1970), discussions were initiated and continued during some 3 yr between Dr. John L. Wheeler (then Animal Scientist, Pastoral Research Laboratory, CSIRO, Armidale NSW, Australia, now retired) and me. Of mutual interest to us was an understanding of the two approaches to grazing research and how the opponent's view of each might be understood and discussed relative to each methods' desirable and undesirable attributes. This 3-yr exchange resulted in a publication (Wheeler et al., 1973) that addressed the rationale for the use of one method of stocking over the other. Considerations were given to potential bias, reliability of data, resources required, and criteria on which one might base the choice of one method over the other. The document provided proponents of both camps' (fixed vs. variable stocking) insight into the other's perspective.

Of note is that the exchange that occurred between Dr. Wheeler and me following the International Grassland Congress, was predicated on a previous acquaintance which occurred in 1963. Dr. Wheeler, having interest in variable stocking, visited the Agronomy Department, Purdue University, where I was then a graduate research assistant, to meet with Dr. G.O. Mott to discuss stocking methods. Before his visit at Purdue, Dr. Wheeler had spent some time at North Carolina State University with Dr. H.L. Lucas and the leaders of the grazing project, then Drs. H.D. Gross (Department of Crop Science) and R.D. Mochrie (Department of Animal Science), in which they discussed and designed several potential grazing trials to address fixed vs. variable stocking. Little did I know at the time of Dr. Wheeler's visit to Purdue that, following a short stint at Texas A&M University, I would become the team agronomist beginning the winter 1967 to participate in those very experiments previously discussed at North Carolina State University. Furthermore, it was the data from one of those experiments that I presented at the XI International Grassland Congress that initiated debate at the Congress.

Flexible Grazing

A natural outflow from the principal of grazing pressure and its relationship to output per animal and per hectare is the concept of flexible grazing. Innovations in grazing management strategies by R.E. Blaser and Associates, such as first and last grazers (Blaser et al., 1969), top and bottom grazers (Bryant et al., 1961), first and last rotational grazers (Blaser et al., 1986), and creep or forward-creep grazing (Blaser et al., 1986) put forth the concept of flexible management in pasture utilization. The approach manipulates animal daily gain and animal grain per hectare while controlling forage utilization (Blaser et al., 1981). The application of managed grazing, available pasture and integrated management, all components of flexible grazing, were probably best achieved in a presentation made by Dr. R.E. Blaser to the 1981 Stobbs Memorial lecture, Brisbane, Australia (Blaser, 1982). Salient points directed to subtropical pastures, but having implication to all pastures, are quoted below:

A pasture grazed and utilized at a constant stocking rate, without conservation, may be readily over or under grazed as a result of variable growth rates due to the plant's response to temperature, and moisture stress. In such set regimes the nutritional needs of grazing animals and management of swards for high yields and quality are ignored.

Variables in objective pasture–animal management systems should be managed rather than fixed.

In my view constant stocking rate experiments should be replaced with variable stocking rates within integrated pasture and animal management systems to overcome the constraints causing low animal production and conversion efficiency of pastures to animal products.

Costly grazing experiments with several constant stocking rates during the entire year cause massive accumulation of stemmy swards and losses in animal weight during winter and spring.
Sward management principles (maintaining yield, quality and desirable botanical components) and the nutritional requirement of ruminants are ignored with constant stocking.
The high growth rates of pasture, exceeding utilization by grazing animals, causes leafy swards to become stemmy.

As a by-chance attendee (participant in a concurrent "Nutritional Limits to Animal Production from Pastures" Symposium, August 1981, St. Lucia, Australia) at the memorial lecture, it was clear that such statements in an environment that practiced predominately fixed stocking were revealing. Considerable discussion was generated and much was learned by all. Clearly, Dr. Blaser was in his element and, with distinction, rose to the occasion.

The concept of flexible grazing accommodates different farming situations (soil, livestock, environment) with an array of vegetation and animal classes to enhance forage utilization for animal production (Blaser et al., 1976, 1986). Addressing the issue of fixed vs. variable stocking (Blaser et al., 1962; Wheeler et al., 1973) has helped to shift attitudes and approaches and flexible grazing is being practiced now where once it would not have been considered.

Measurements in Recent Grazing Research

Grazing research conducted in the early years in the humid East was generally oriented toward an understanding of what animal response might be expected from various pasture species or species mixtures. Frequently, measurements consisted of only animal weights allowing the computation of animal daily gain, gain per animal, and animal gain per hectare. Such information was urgently needed and served an important role in developing grazing systems. More recently, however, Burns et al. (1989) put forth a rather demanding list of measurements in the conduct of grazing trials that would move the output beyond simply addressing the question of *what might be expected* to providing insight as to *why differences observed among treatments actually occurred*. Many of these measurements were previously highlighted in a special session held in conjunction with the XV International Grassland Congress held in Kyoto, Japan, 1985, with 14 full-length papers published as a compendium (Horn et al., 1987). The role of these measurements in more traditional grazing experiments has been placed into perspective by Sollenberger and Burns (2001), and the use of more detailed measurements addressed by Burns and Sollenberger (2001). Recent examples of the application of many of the measurements described by Burns et al. (1989) can be found, for example, in Fisher et al. (1991), Burns et al. (1991, 1992), and Newman et al. (2002, 2003).

IMPORTANT INNOVATIONS

Methodologies are noted below that have been developed and have benefited, either directly or indirectly, the conduct of grazing research in the humid Eastern USA and subsequent understanding of animal responses.

Multiple Assignment Tester System

In the humid East, a pasture system will generally consist of two or more forage species of different physiological type (i.e., annual and perennial legumes and grasses with the grasses of C_3 and C_4 metabolism). Because of facility requirements and cost constraints, grazing research has frequently focused only on components of a system as opposed to the season-long system. The multiple assignment of tests animals was proposed by Matches in 1969 to evaluate potential carryover affects, either positive or negative, between or among components that make up a total pasture system as the season progresses (Matches, 1969). The concept was viewed as providing the producer with more reliable data, and having potential cost savings on the research side with some statistical advantages. The approach was validated in 1974 (Matches et al., 1974) and has been recently used in evaluating two different, two-component pasture systems (Moore et al., 2004).

Nondestructive Estimates of Herbage Mass

Traditionally, the mower strip or samples harvested by hand have been used to obtain estimate of herbage mass or available pasture. Defoliation by mechanical harvesting, however, has forage-species specific complications regarding stubble height and subsequent perturbations in animals grazing behavior. The falling disc meter (Bransby et al., 1977) and nondestructive methods, such as the capacitance meter (Toledo et al., 1980), have been introduced and used to estimate herbage mass with minimal disturbance of the pasture canopy.

Ingestive Behavior (Diet Particle Size)

Animals consume their daily ration one mouthful at a time. In a pasture setting, animals determine their daily diet intake through selective grazing within the constraints of the herbage mass allowed. The quality of the daily selected diet determines animal daily performance.

Ingestive mastication by the grazing animal results in particle breakdown with differences obtained in particle size proportion among forage species (Pond et al., 1984, 1987). This carries implications in forage quality and subsequent animal performance as noted by Burns and Sollenberger (2002).

Removing Antiquality Constituents

Structural inhibitions and nonstructural components of some forages grown in the humid USA have resulted in antiquality responses in the animal (Moore and Mott, 1973; Marten, 1973; Bush and Buckner, 1973; Burns, 1978; Thompson et al., 2001). Continued research in these areas, however, has had major impact on the quality of some specific forage species.

Tall Fescue

Poor herd performance on tall fescue pastures were noted as early as 1950 in Ohio (Pratt and Hayes, 1950). Later, in 1973, severe toxicosis was noted in cattle grazing one pasture in Georgia, but not in cattle grazing three adjacent pastures. The pasture with animals showing toxicosis had fungal endophyte readings of near 100%, whereas infection levels of the adjacent three pastures were much lower (Bacon et al., 1977). It was noted later by Hoveland et al. (1980) that paddocks which averaged 18% endophyte infection supported steer daily gains that were 51% greater, compared with pastures that were 80% infected. This relationship was further verified in 1983 when Hoveland et al. (1983) showed steer average daily gain and gain per hectare, respectively, to be 66 and 28% greater compared with steers grazing pastures that were 94% infected. Subsequently, two improved tall fescue cultivars that are endophyte free have been developed and released as 'Jesup' (Bouton et al., 1997) and HiMag (Sleper et al., 2002). These same cultivars with a novel, nontoxic endophyte present have been named 'MaxQ' and 'ArkPlus', respectively, and have been shown to have potential in production systems (Bouton et al., 2002; Nihsen et al., 2004; West et al., 2003).

Reed Canarygrass

Initial identification was made of a negative relationship between alkaloid concentration in reed canarygrass and selective palatability with sheep (Simons and Marten, 1971; Marten, 1973) and of total indol alkaloids with lamb average daily gains (Marten and Jordan, 1974). Physiological upset in the form of diarrhea was observed with both sheep and steers when animals consumed tryptamine (1H-indole-3-ethanamine)–carboline [9H-pyrido(3,4-b)indole] vs. gramine (1H-indole-3-methanamine) containing plants (Marten et al., 1976). A safe threshold level was determined for indole alkaloid concentrations (Marten et al., 1981) and a nontoxic germplasm was released in 1983 (Hovin and Marten, 1983).

Bermudagrass

The improvement in dry matter digestion of bermudagrass through breeding is evidenced by the release of the cultivar 'Tifton 85' (Burton et al., 1993). In comparison with 'Coastal', the dry matter digestion was appreciably increased and attributed mainly to a change in cell wall chemistry (Mandebvu et al., 1999a), permitting the cell wall constituents to be more easily degraded by the rumen flora (Mandebvu et al., 1999b).

Marker Technology for Estimating Pasture Daily Intake

The performance of the grazing animal is closely related to its daily digestible dry matter intake. This value, however, requires an estimate of daily dry matter intake and its digestibility, of which the former is generally considered the most influential (Noller, 1997; Lippke, 2002). A major constraint to the evaluation of pastures has historically been an inadequate method to obtain either a precise or an accurate estimate of daily dry matter intake by the grazing animal. This constraint remains today. Internal markers have been used in the historic past with limited success (Lippke, 2002). Rare earth elements have also been investigated as potential external markers (Pond et al., 1989; Ellis and Beever, 1984) and have been determined to be useful (Burns et al., 1991, 1992; Lippke, 2002).

A LOOK AHEAD

Grazing research, as an area of experimentation, emerged in the humid-Eastern USA during the late 1950s to the mid-1960s. Since then, a number of theoretical concepts and some tools to examine the plant–animal interface have been developed and were discussed. Since the mid-1960s, a number of grazing experiments have been conducted but most were designed to address the *what if?* question. For example, if specific species were grazed a certain way, what might be expected in terms of daily animal gain and animal gain per hectare? Those studies, although useful, lacked the essential plant and animal measurements to understand why specific animal responses occurred. As a consequence, predictive responses in grazing research generally remain unrealized.

Yet, forages and grasslands, recently designated by USDA as a national, natural resource, are paramount in retaining a healthy environment. This vast resource, found in every county across the humid East, accommodates soil conservation, nutrient management, clean streams and rivers, wildlife diversity (habitat), wildlife populations (food), a feed source for wild and domesticated herbivores, biomass, and plant diversity across the landscape. This huge natural resource is renewable and, therefore, requires and justifies appropriate types and degrees of management. Brief mention of high-priority areas for grazing research and associated major constraints are noted below.

Priority Areas for Grazing Experimentation

Areas Awaiting Further Understanding

General areas within the plant–animal interface worthy of further understanding are (i) the relationship between plant persistence and grazing defoliation (frequency and intensity) relative to pasture productivity, (ii) the interaction between plant species with its associated morphology and constituent nutritive value and animal daily dry matter intake, (iii) the relationship between the diet ingested by the grazing animal and subsequent particle breakdown with utilization of the soluble and fiber fractions (including concentration, form, and ratios) reflected in daily animal response and, (iv) the interaction between herbage mass with its nutritive value and subsequent changes in selective and ingestive grazing behavior.

Determinations Needed

Application of present methods, either directly or through modification, is warranted to determine (i) daily dry matter intake of the free-grazing animal [recently developed methodology from Australia using alkanes holds considerable promise in this area (Lippke et al., 1999; Lippke, 2002)], (ii) the role of modified pasture plants in animal production systems, (iii) reliable, predictive plant–animal relationships, including the role of near-infrared spectroscopy (NIRS) in estimating daily dry matter intake and its digestibility for the grazing animal, (iv) grazing management strategies to favor wildlife populations and diversity, and (v) grazing species that will serve the urban and rural communities and will add plant diversity on the landscape.

Major Constraints

Although constraints occur in all areas of biological research, two have and continue to be paramount in thwarting the advancement of grazing research and remain a major concern. These are research teams to adequately address the biologically, complex plant–animal interface and adequate public funding for sustained programs of sufficient scope (size and depth) to realistically conduct forage–herbivore research. These two areas are briefly touched on below.

Team Research

Grazing experimentation to address the underlying interaction between the pasture and the animal requires expertise in the areas of plants, animals, soils and analysis. More specifically, expertise in several disciplines within each of these areas is needed. Team research is frequently promoted verbally and often suggested or required in project formulation or in grant submissions. Although functional programs can be structured around administrative (agency and/or departmental) boundaries to permit team research (Fig. 2), such programs remain extremely fragile. This can be reduced by the formation of formal forage–animal thrusts of program scope and size. In a university setting, this may occur as an institute or a center. Institutes, however, come and go because of the way they are frequently structured regarding administrative responsibilities, associated individuals, and the volatility of funding. The concept within USDA-ARS is more easily addressed through the formation of regional centers with a plant–animal focus. In both cases, team members must be carefully selected and subsequently evaluated. Unfortunately, the present reward system essentially undermines the team concept. Individuals and their personal programs are generally evaluated (i.e., author rank on publications, role in research, grant funds awarded, perceived depth of research, technology transfer, etc.) for accomplishments as opposed to those of the team, and an individual in a true-team effort may be negatively impacted. This, and other issues were addressed a number of years ago (Burns et al., 1988), and although some recent indications are that the process may be reevaluated, it remains a major dilemma. However, team research in the grazing area may become a moot point in the future because of the recent decline in adequately trained students with a strong interest in either forages or in the forage-animal area.

Support for Grazing Research

Plants are primary producers, that is, they fix carbon directly, and to a large extent support a wide array of herbivores that are harvested and sold for their meat, milk, fiber, or used for recreation. Most industries based on these value–added products have organized into commodity groups that socially and politically promote the development and marketing of these products. Forages and grasslands, however, not considered a part of the animal industry, are essentially left suspended behind the scene regarding their role in the production of value-added products. Although state grassland councils and grassland initiatives exists, most have common membership with value-added commodity groups, and the later dominates in terms of support (social, political, and financial). This has been and continues to be a major dilemma.

The future of grazing research appears to reside with a greater commitment to stable, long-term funding. It is unlikely that either the private sector or granting agencies will entertain funding for this important area of research. Consequently, federal funds provided through the research arm of USDA (i.e., Agricultural Research Service) in cooperation with selected land grant universities will be required. University selection needs to be based on some matching proportion of state funds through universities that are dedicated to the land grant mission. This arrangement will permit USDA to meet its mandate of providing both research findings for sister federal agencies, and regional information for stakeholders and consumers. Furthermore, when done in concert with local universities that are intent on fulfilling the land grant mission, technical training in the area is possible and technology transfer greatly enhanced for the best use of this vast natural resource with minimal duplication for the general good of the American people.

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